Description

COOLING SYSTEM FOR AN ELECTRIC MOTOR

Technical Field

[01] The present disclosure is directed to a cooling system for an electric motor, and more particularly, to a cooling system for liquid cooling an electric motor.

Background

[02] Traditionally, electric motors have been used in stationary applications. Because of this, the volume or size of electric motors has not been critical, and sufficient cooling of the electric motors could be achieved by using air, with or without fins, and large motor housings, serving as heat-sinks. More recently, electric motors have been used in mobile applications, such as on automobiles or work machines. Because mobile applications put a premium on smaller size and lower weight, these motors are more power dense and therefore more difficult to cool than their stationary counterparts.

[03] As the size of the motors is decreased, air cooling alone is often insufficient to maintain temperatures of the motors at acceptable levels. Furthermore, because the motors are now often on mobile vehicles, they are subject to a variety of temperature ranges and environments. The air may be dusty or dirty, or the motors may become caked in mud, reducing the ability to air cool the motors. In order to maintain cooling consistency in different environments, electric motors have been developed using liquid cooling.

[04] Initial designs for liquid cooled electric motors included forming fluid passages through the motor housings during casting. In use, as the housings draw heat from motor components in the housing, the heat was drawn away from

the housing by the liquids forced through the housing passages. However, casting such passages in housings is difficult and expensive.

[05] One attempt to solve the heating problem is shown in U.S. Patent No. 5,931,757 to Schmidt. Schmidt discloses an electromechanical transmission for receiving power from an engine. It includes in its outer surface, a single annular channel where oil may accumulate next to a stator in an electric motor system. Although easier to manufacture than cast interior passages, such a single channel may not provide sufficient cooling for the electric motor, and may provide inconsistent heat zones in the stator.

[06] The present invention is directed to overcoming one or more of the deficiencies in the prior art.

Summary of the Invention

[07] In one aspect, the present disclosure is directed to a cooling system for an electric motor. The cooling system may include a cooling duct formed between a cooling jacket and a separate component surface. The separate component surface may define at least a portion of a wall of the cooling duct. The cooling duct may be configured to direct a cooling liquid along at least a portion of the separate component surface and draw heat from the electric motor. An inlet port may be in fluid communication with the cooling duct. The inlet port may be configured to receive the cooling liquid and to introduce the cooling liquid to the cooling duct. An outlet port may be in fluid communication with the cooling duct.

[08] In another aspect, the present disclosure is directed to an electric motor having a cooling jacket with an inner surface having at least one cooling groove. A stator may be disposed within the cooling jacket, and may have an outer surface in contact with at least a portion of the inner surface of the cooling jacket. The cooling groove and the outer surface of the stator may form a cooling duct. The cooling groove may be spiraled such that the cooling duct is configured to direct a cooling liquid at least partially in an axial direction.

Brief Description of the Drawings

[09] FIG. 1 is a pictorial representation of an electric motor in accordance with the present disclosure.

[10] FIG. 2 is a pictorial representation of the cooling ducts formed by the stator and cooling jacket.

[11] FIG. 3 is a pictorial cross-sectional view of an electric motor.

[12] FIG. 4 is an enlarged pictorial cross-sectional view of a portion of the electric motor of FIG. 1.

[13] FIG. 5 is a pictorial cross-sectional view of a second embodiment of an electric motor.

[14] FIG. 6 is an enlarged pictorial cross-sectional view of a portion of the electric motor of FIG. 5.

Detailed Description

[15] Reference will now be made in detail to embodiments of the present invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[16] An exemplary embodiment of an electric motor 100 is illustrated in FIG. 1. The electric motor 100 may be used in any application requiring an electric motor, including a mobile application, such as on a work machine or other vehicle. The electric motor 100 may include a stator 102, a rotor 104, and a shaft 106, all housed in a cooling jacket 108.

[17] The stator 102 may be formed of a series of thin laminates placed side-by-side, along with windings formed of conducting material. The stator 102 may have a cylindrical shape with an inner surface 110 and an outer surface 112. Each end of the stator 102 may include end windings 114, formed of a series of wound conductive material.

[18] The rotor 104 may be housed within the stator 102. It may be formed of typical materials for an electric motor, and may be configured to rotate within the stator 108 to create torque. Formed in a cylindrical shape, the rotor 104 may have an open center to be attached to the shaft 106.

[19] The shaft 106 may extend through the center of the rotor 104, and may define a motor axis 116. The motor axis 116 may be an axis for the stator 102, the rotor 104, and the cooling jacket 108. The shaft 106 may be fixed to the rotor 104 so that as the rotor 104 rotates, it drives the shaft 106. Likewise, when the shaft 106 rotates, it may drive the rotor 104.

[20] The cooling jacket 108 may be a cylindrical housing for the stator 102. The cooling jacket has an inner surface 118 and an outer surface 120, and may be formed to be an interference fit onto the stator 102. Accordingly, the inner surface 118 of the cooling jacket 108 may be in direct contact with the outer surface 112 of the stator 102.

[21] End plates 122 may connect to each end of the cooling jacket 108, sealing closed the ends of the motor 100. The inner surface 118 of the cooling jacket 108, together with the end plates 122, may define an operating region 124. The stator 102, the rotor 104 and the shaft 106 may be housed within the operating region 124.

[22] The cooling jacket 108 may contain a cooling system 126 for reducing heat in the electrical motor 100. The cooling system 126 may include a groove system 127 and a fluid injector system 152. In the embodiment shown, the groove system 127 includes grooves 128 formed in the inner surface 118 of the cooling jacket 108. The grooves 128 may be formed to extend about the inner diameter of the cooling jacket 108, in a region in contact with the stator 102. Accordingly, the grooves 128 may extend around the outer surface 112 of the stator 102. In one exemplary embodiment, the grooves 128 may be spiraled along a length of the stator 102 in manner that the grooves extend, at least in part, axially along the motor 100.

[23] An inlet port 130 and an outlet port 132 (represented in FIG. 2) may extend through the outer surface 120 of the cooling jacket 108 and may be in fluid communication with the groove 128. The inlet port 130 allows a cooling liquid, such as oil, to enter the grooves 128, while the outlet port 132 forms an exit path for the cooling liquid that has passed through the grooves 128.

[24] The grooves 128 and the outer surface 112 of the stator 102 together define ducts 134. In the exemplary embodiment shown in FIG. 1, the ducts 134 include at least one surface formed of the outer surface 112 of the stator 102. The other surfaces of the ducts 134 are formed by the cooling jacket 108. The ducts 134 may be rectangular as shown, or alternatively, may have any other shape, such as, for example, a trapezoidal shape, or an arch shape.

[25] The ducts 134 may be configured to receive and direct the cooling liquid around the stator 108. Because the ducts are formed in part by the grooves 128, the ducts 134 may be spiraled along the stator 102 so that one portion of the ducts 134 may be axially offset from another portion of the ducts 134. Accordingly, the cooling liquid in the ducts 134 may flow in an axial direction as well as a circumferential direction. The size of the ducts 134 are defined by the size of the grooves 128, which may be formed to allow the cooling liquid to flow through the ducts 134 at a velocity sufficient to provide a desired cooling capacity to the electric motor 100. Further, the spiral of the grooves 134 may provide even, distributed cooling along at least a portion of the length of the stator 102. The spirals can be connected in series with a small number of connections. This allows the fluid velocity to be maintained with a minimum of back pressure.

[26] A groove width 136, representing the gap of the grooves 128, may be measured axially along the stator 102. The groove width 136 may be selected based upon a desired velocity and/or a desired cooling liquid flow through the ducts 134. In one exemplary embodiment, the grooves 128 may be formed to have a groove width 136 substantially the same as a land width 138. As used in

this disclosure, the term "land width" is the axial distance of the inner surface 118 of the cooling jacket 108 between adjacent grooves 128. In some exemplary embodiments, a land width to groove width ratio may be within a ratio range of 2:3 and 3:2. In the exemplary embodiment shown, the land width to groove width ratio is about a one-to-one ratio. However, the grooves 128 may be formed to have any different land width to groove width ratio that is appropriate for a particular motor design.

[27] FIG. 2 shows one example of the ducts and a circulating pattern of a cooling liquid therethrough. In this exemplary embodiment, the ducts are formed in three spirals 140 extending from the inlet port 130 to the outlet port 132. Accordingly, the cooling liquid flows through the three spirals 140, designated with three arrow types. The three arrow types represent the direction of flow through the ducts, and may be used to distinguish one spiral duct from another. From the inlet port 130, a pressurized cooling liquid may enter a first duct 142 having a solid arrow. The cooling liquid may be circulated through the first duct 142 for a length, such as, for example, two and one-half revolutions about the stator 102 (not shown in FIG. 2). The first duct 142 may merge with a second duct 144 designated by a dashed arrow at a first intersection 146 at one end of the cooling system 126. The cooling liquid flow may enter the second duct 144, flowing in a direction opposite that of the direction in the first duct 142.

[28] The cooling liquid may be circulated through the second duct 144 for a length, such as, for example, two revolutions about the stator 102. The second duct 144 may merge with a third duct 148 designated by a dotted arrow at a second intersection 150 at a second end of the cooling system 126. The cooling liquid flow may again reverse directions and flow in a direction opposite that of the second duct 144. The cooling liquid may be circulated through the third duct 148 for a length, such as, for example, two and one-half revolutions about the stator 102. The outlet port 132 may be located at an end of the third duct 148, and may be configured to direct the cooling liquid out of the cooling system 126.

Accordingly, although more than one cooling duct may extend along the stator 102, only one inlet port and only one outlet port are necessary to cool the stator 102.

[29] FIG. 3 is a transverse cross sectional view of the electric motor 100. As explained above, the exemplary embodiment described includes three grooves 128 formed in the cooling jacket 108 to create the ducts 134 between the cooling jacket 108 and the stator 102. In the embodiment shown, the three grooves 128 are spiraled and offset 120° apart. As explained above with reference to FIG. 1, the land width 138 may be substantially equivalent to the groove width 136, thereby providing substantially a one-to-one ratio. The three grooves 128 may effectively distribute the compression forces applied against the stator 102 by the interference fit cooling jacket 108 so that the laminates forming the stator 102 do not excessively move or change the shape of the inner surface 110. However, the cooling jacket 108 may include more or less than three grooves in the cooling system 126.

[30] Returning to FIG. 1, the cooling system 126 of the electric motor 100 may also include a fluid injector system 152 to spray a cooling liquid on the stator 102 and/or the rotor 104. The fluid injector system 152 may include an annular ring 154 formed in the end plate 122, a sealing plate 156, and a port 158. The fluid injector system 152 may also include one or more fluid passages 160 serving as nozzles extending through the end plate 122.

[31] The annular ring 154 in the end plate 122 may be formed about the axis 116 in an exterior surface 162 of the end plate 122. The sealing plate 156 may be attached to the exterior surface 162 of the end plate 122, and may be sized to fit over the annular ring 154, forming a cavity 164. The sealing plate 156 may be sealed against the end plate 122 such that any cooling liquid within the cavity 164 does not leak. The port 158 may be an inlet to the cavity 164, allowing the cooling liquid into the cavity 164.

[32] The fluid passages 160 may extend through the end plate 122 from the cavity 164, and allow passage of the cooling liquid into the operating region 124 of the electric motor 100. The fluid passages 160 may have a relatively small diameter, allowing them to serve as nozzles that deliver the cooling liquid into the operating region 124. In one embodiment, the fluid passages 160 direct the cooling liquid directly at an end of the rotor 104. Accordingly, the cooling liquid may be used to maintain the operating temperature of the rotor 104 at an acceptable level. The passages 160 may extend through the end plate 122 in a direction to deliver cooling liquid on any desired area or component in the operating region 124. In one exemplary embodiment, the passages are configured to spray cooling liquid onto the end windings 114 of the stator 102.

[33] In another exemplary embodiment, shown in FIG. 4, a second annular ring 170 may be formed in the end plate 122 at a radius that corresponds with the end windings 114 on the stator 102. In this exemplary embodiment, the second annular ring 170 is formed as a radial groove in an edge 172 of the end plate 122. The second annular ring 170 may be sealed between the cooling jacket 108 to form a second annular cavity. Second passages 174 may be formed through the end plate 122 for passage of cooling liquid from the second annular ring 170 into the operating region 124. An inlet port 176 may be formed in the end plate 122 to allow liquid to flow into the second annular ring 170, and through the second passages 174. Because the end windings 114 on the stator 102 may maintain a high temperature during operation of the motor 100, the passages may be located in a manner that delivers the cooling liquid directly on the end windings 114. It should be noted that any of the passages 160, 174 disclosed with reference to the present invention may include nozzles or inserts placed to direct cooling liquid from the annular rings 154, 170 into the operating region 124. Fluid piping 166 may direct the cooling liquid into the annular rings 154, 170 and/or the ports 130, 176, and may connect to a pump (not shown) to pressurize the cooling liquid.

[34] FIGs. 5 and 6 show another exemplary embodiment of the electric motor 100. In this exemplary embodiment, the cooling jacket 102 includes grooves 128 formed in the outer surface 120 of the cooling jacket 108, rather than the inner surface 118. In this embodiment, an exterior sleeve 200 is placed around the outer surface 120 of the cooling jacket 108. The grooves 128 formed in the outer surface 120 of the cooling jacket 108, together with the exterior sleeve 200, form the ducts 134. Accordingly, in this embodiment, the ducts 134 are not formed against the stator 102, but instead are formed against the exterior sleeve 200.

[35] As described above with reference to FIG. 1, the grooves 128 may be formed in a spiral shape about the cooling jacket 108. The inlet and outlet ports (not shown in FIGs. 5 and 6) provide fluid access to the ducts 134. In this exemplary embodiment, the inlet port may be formed through a central region of the cooling jacket 108 and the exterior sleeve 200 to provide access to the grooves 128. The grooves 128 may be formed to spirally separate in axially opposite directions away from the central region of the outer surface 120 of the cooling jacket 108. One advantage of forming the ducts 134 with the exterior sleeve 200, rather than the stator 102, is that when contaminates or debris enter the cooling ducts 134 with the cooling liquid, the exterior sleeve 200 may be easily removed to provide access to the grooves 128 for cleaning. Furthermore, manufacturing is simplified, as cooling grooves 128 formed in the outer surface 120 of the cooling jacket 108 are easier to form than cooling grooves 128 formed on the inner surface 118 of the cooling jacket 108.

[36] In this exemplary embodiment, the fluid injector system 152 may include an annular ring 202 and passages 204. The annular ring 202 may be formed between the cooling jacket 108 and the exterior sleeve 200, and may be in fluid communication with an end of the cooling duct 134. The passages 204 may extend through the cooling jacket 108 between the annular ring 202 and the operating region 124 of the electric motor 100. These passages 204 may operate

as nozzles as part of the cooling system 126 to allow the cooling liquid to spray onto the components within the operating region 124. In one embodiment, the passages 204 are configured to spray cooling fluid directly onto the end windings 114 of the stator 102.

[37] As shown in FIG. 6, this exemplary embodiment may include a deflector 206 formed at an end of the passage 204. The deflector 206 may be formed of the cooling jacket 108, the end plate 122, or other portion of the motor 100. The deflector 206 may be shaped to deflect and spread the jet of cooling liquid from the passages 204 into a pattern to cool a larger area of the end windings 114. Deflecting the cooling liquid onto the end windings 114 of the stator 102 may reduce the possibility of erosion due to a continuous and direct flow of liquid onto the stator 102.

Industrial Applicability

[38] In use, the cooling liquid may be pressurized by a pump (not shown) and directed through the fluid piping 166 into the inlet port 130 and/or the port 158. The cooling liquid may be directed into the ducts 134 formed by the outer surface 112 of the stator 102 and the grooves 128 of the cooling jacket 108, or alternatively, by the exterior sleeve 200 and the grooves 128. The grooves 128 may be formed in a manner that directs the cooling liquid to pass over a length of the stator 102 in both an axial and a radial direction.

[39] In one embodiment, the grooves 128 may be formed so that the cooling liquid passes back and forth in an axial direction along the outer surface of the stator 102. The cooling liquid may exit the ducts 134 from the outlet port 132.

[40] In addition to cooling the electric motor 100 using the cooling ducts 134, passages 160, 204 may spray cooling oil directly to the ends of the stator 102 and/or the rotor 104. The cooling liquid may be pressurized by a pump and forced through fluid piping 166 into annular cavities 164 or rings 202 formed between end plates 122 and sealing plates 156, or between the exterior sleeve 200

and the cooling jacket 108. The pressurized cooling liquid may pass through the passages 160, 204 into the operating region 124 of the electric motor 100. The cooling liquid may be injected directly on the end windings 114 of the stator 102, as the end windings 114 may be one of the high temperature components in the electric motor 100. Cooling liquid sprayed on the rotor 104 may splash or may be flung radially outward toward the end windings 114 of the stator 102, cooling not only the rotor 104, but also the end windings 114 of the stator 102. Cooling liquid in the operating region 124 may be allowed to drain down into an oil pan at a bottom or end of the electric motor 100.

[41] The system for cooling an electric motor may be used with any electric motor in any environment. It is particularly conducive to cooling electric motors used on mobile vehicles or in mobile applications. The cooling system increases the cooling efficiency of the motor without increasing the size or weight of the electric motor.

[42] It will be apparent to those skilled in the art that various modifications and variations can be made in the disclosed system and method without departing from the scope of the invention. Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope of the invention being indicated by the following claims and their equivalents.